Operational Experience with the CMS Pixel Detector

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The Compact Muon Solenoid

- From Inside ➔ Out
  - Silicon Tracker (Pixels ➔ Strips)
  - Electromagnetic Calorimeter
  - Hadronic Calorimeter
  - 3.8T Solenoid
  - Muon systems (RPC, CSC, DT)

- 15 m in diameter
- 21 m long
- 12500 tons in all
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CMS Pixel detector

Silicon sensors:
Bump bonded to PSI 46 Read-Out Chips (ROCs)
n in n for under-depleted operation and Lorentz drift
265-270 μm thick

Barrel (PSI):
0.78 m²
3 layers @ r = 4.3, 7.2, 11.0 cm
11520 ROCs = 48M pixels

Forward (FNAL):
0.28 m²
2 discs on each end
z = ±34.5 & ±46.5 cm
4320 ROCs = 18M pixels
Barrel Pixels (BPix)

Forward Pixels (FPix)

3 point tracking to $|\eta| \sim 2.4$
The CMS Pixel Read Out Chip

- Developed at PSI
  - Manufactured by IBM
- 26 double columns x 80 rows = 4160 pixels (100x150 um)
- Zero suppression on chip
  - Each pixel has 4 trim bits
- Data buffered on chip until a trigger arrives
- 26 DACs for tuning chip performance

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VME hardware controlled by Linux
PCs running custom online software
written in XDAQ framework

Online software:
- Configures detector
- Implements calibration algorithms
- Monitors DAQ hardware during data-taking
Analog readout

- 1 module → 1 or 2 readout links (optical fiber to FED)
- TBM adds header (incl. event counter) and trailer (status)
- Each ROC always sends header
  - For a hit above threshold:
    - 5 clocks to encode pixel address (base 6)
    - 1 clock for pulse height (saturation at ~1.5-2 MIPS)
- Our most frequently run calibrations are to ensure proper decoding by the FED of these analog signals
Detector Status

- **Spring 2009:** FPix removed from CMS and 5% that stopped working after installation was repaired
  - Also added pyrolytic graphite “cold fingers” to put lasers and cooling in thermal contact
- **2009:** some FPix channels had to be disabled because the analog signals became very slow, leading to garbled decoding
- **Current fraction taking good data:**
  - 98.8% of BPix
  - 96.4% of FPix
  - Overall: 98.2% of pixel detector
Minimization of absolute thresholds

- Adjust \( V_{cThr} \) DAC (8 bit) on each ROC to minimize threshold
  - Separately, thresholds are equalized within each ROC (trim bits)
- Test pixel response using calibration capacitor
  - Capacitor \( \rightarrow \) electrons conversion calibrated using \( X \) rays
- Threshold for 2010 run:
  - 2460 electrons (MIP is 20k e-)
  - FPix and BPix very similar

![Graph showing pixel hit efficiency vs. charge injection DAC setting](image1)

![Histogram showing mean ROC threshold](image2)
In-time thresholds

- The readout window of the ROC is one bunch crossing (25 ns)
- A particle depositing charge above the absolute threshold will leave a hit in the detector eventually
  - Relevant for occupancy at high luminosity
- To contribute to reconstruction of a track, the particle must leave a hit that goes above threshold in the correct bunch crossing
  - The effective threshold is ~800 e- higher than the absolute threshold
    - This difference was tuned using one of the ROC’s DAC settings

• Need to maintain efficiency for fast (high pulse height) signals
• Want to have as much efficiency as possible for slow (low pulse height) signals in order to maximize resolution via charge sharing
Preliminary fine delay scan

- Must adjust our readout timing so that the LHC clock is aligned with the signal in the detector
- Can only be done with beam data

- **December 2009:** In the first substantial colliding beam fill, did a preliminary scan of the delay settings
- **Goal:** ensure that selected delay gives maximum efficiency
- **Online DQM plots used to provide immediate feedback in control room.**
- 5 points; 5-15 min per point
- Selected timing (+6 ns) later confirmed with offline analysis

**Look for maximum cluster charge** (one of several observables)
Done early in 2010 run

Goals:
- Optimize resolution by moving later on high efficiency plateau (get more low pulse height signals into correct bunch crossing)
- Adjust intradetector timing
- Analysis done offline

Note: “efficiency” shown below is useful only for relative comparison. It is not an absolute measurement!

Timing from 2009 scan
Operations with beam

- For injection, ramp, beam adjustments: **our bias voltage is OFF**
  - Turn on bias after LHC declares “Stable Beams”
  - Software for detector control (power supplies) is connected to LHC machine modes – **our voltages are automatically lowered if necessary**

- Beam Radiation Monitoring system is connected to an automatic beam abort
  - We monitor status of BRM counters continuously
  - **In practice, beam background has not been a problem yet** (from a detector safety point of view)
    - LHC beam is still of relatively low intensity, and losses have been small
Beam background

- Extremely large events grazing the length of the barrel
- Creates very high occupancy in a contiguous piece of the detector

Schematic of data flowing from optical link into the FED

Normal:

```
Trigger -> Data -> Trigger -> Data -> Trigger
```

Large event:

```
Trigger -> Data from large event -> Trigger -> Data
```

The FED firmware had to be modified to gracefully cope with this situation – throw out the data from the event after the large event.

These backgrounds present an ongoing challenge for the DAQ as rates increase.
More on beam background

- Number of pixels over threshold:
  - Function of $\sqrt{s}$
  - Compared to min bias MC

→ Preliminary simulations of beam gas interactions give a fluence estimate compatible with the observed rate of these events
• Corrected for track impact angle
• Data/MC agreement quite good!

See Simon’s talk for much more!
Summary

- We spent 2009 optimizing the detector performance
  - Also, >1 month spent in 24/7 cosmic data taking (CRAFT09) provided time to refine: operating procedures, online DAQ software, DQM software, etc
- Christmas came early in December 2009
  - Pixel detector played a key role in first physics results
- Beam backgrounds have provided a (not unexpected) challenge
  - Doing OK now, more issues could arise as intensity increases
- Detector has been timed in and is delivering high quality physics data
  - Preliminary data/MC comparisons look promising
Backup slides
FPix Maintenance in Spring 2009

- After installation in 2008, several problems appeared
  - Faulty crimps in LV cable: 3.1% of FPix affected
  - Shorted HV connection: 2.2% of FPix affected
- FPix laser drivers suffered from temperature instability
  - Light output is a strong function of temperature
  - No thermal connection between cooling and lasers
- FPix removed from CMS in March 2009
  - Transported to CERN Meyrin site for maintenance
  - Channels affected by LV, HV problems recovered
  - Pyrolytic graphite "cold fingers" added to thermally couple lasers to cooling pipes
More details on large event DAQ issues

- ROC sends hits for a given trigger until all are sent
  - In principle this can take $\mu$s or even ms
    - For the Phase 1 upgrade ROC it is planned to change this

- Typical sequence of events:
  - Size of event passes hit limit on FED
    - Hit limit is adjustable within limits of buffer size
    - At this point FED says “Overflow” and stops listening to that channel
  - Another trigger arrives
    - Data from old event still flowing in from ROCs
    - FED goes looking for new TBM header
      - After 80 clocks, it will give up (“Timeout”)

- Key to staying in sync is to count the timeouts, and ignore that many subsequent events from the front end
  - For this to work, there needs to be adequate time without triggers for the data to flow in
    - There are various paths here; we are pursuing different strategies
Gain calibration

- Pixel-by-pixel fits of pulse height response

Linearity of response and pedestals are adjusted using DACs

Graphs showing pixel-by-pixel fits of pulse height response.